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(54) **OBJECT DETECTION APPARATUS, METHOD FOR CONTROLLING THE OBJECT DETECTION APPARATUS, AND STORAGE MEDIUM**

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G06T 7/20 (2006.01)

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CPC *G06K 9/00577* (2013.01); *G06K 9/00295* (2013.01); *G06T 7/208* (2013.01); *G06T 2207/10016* (2013.01); *G06T 2207/20016* (2013.01); *G06T 2207/20076* (2013.01)

(58) **Field of Classification Search**
None
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(57) **ABSTRACT**

An object detection apparatus comprises a detection unit configured to calculate a detection likelihood from each of the plurality of frame images obtained by an image obtaining unit, and to detect a target object from each of the frame images based on the detection likelihood; and a tracking unit configured to calculate a tracking likelihood of the target object from each of the plurality of frame images, and to track the target object over the plurality of frame images based on the tracking likelihood, wherein the detection unit detects the target object from the frame images obtained by the image obtaining unit based on the tracking likelihood of the target object that is calculated by the tracking unit from the frame images, and the detection likelihood of the target object that is calculated by the detection unit from the frame images.

9 Claims, 8 Drawing Sheets
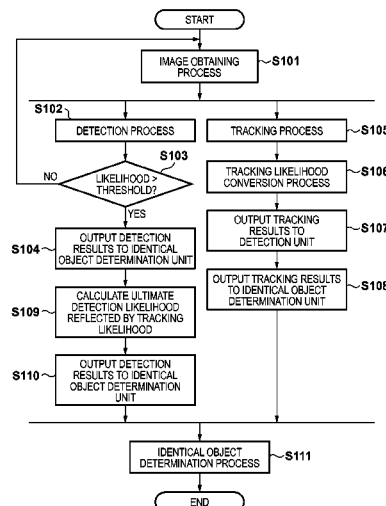
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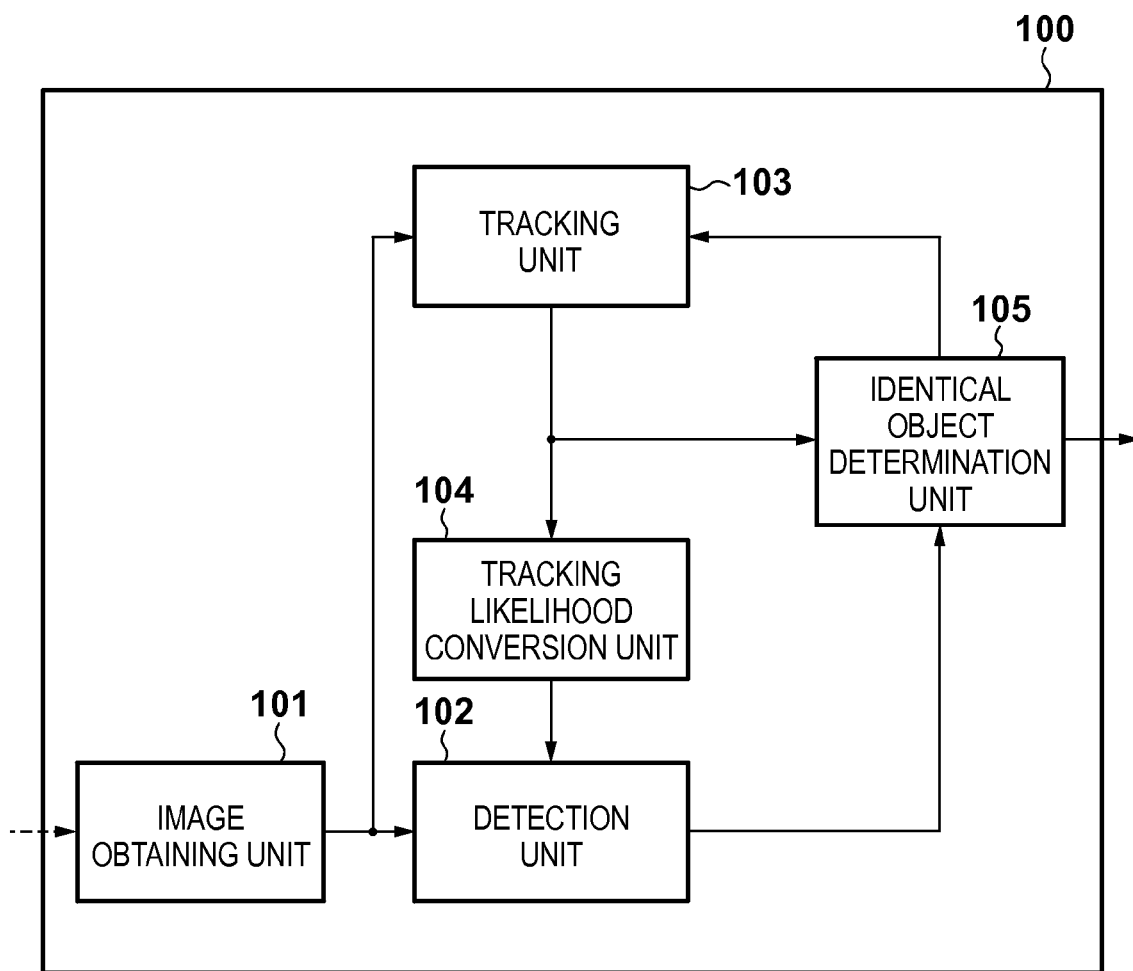U.S. Appl. No. 13/572,342, filed Aug. 10, 2012; Inventors: Shiozaki, et al.

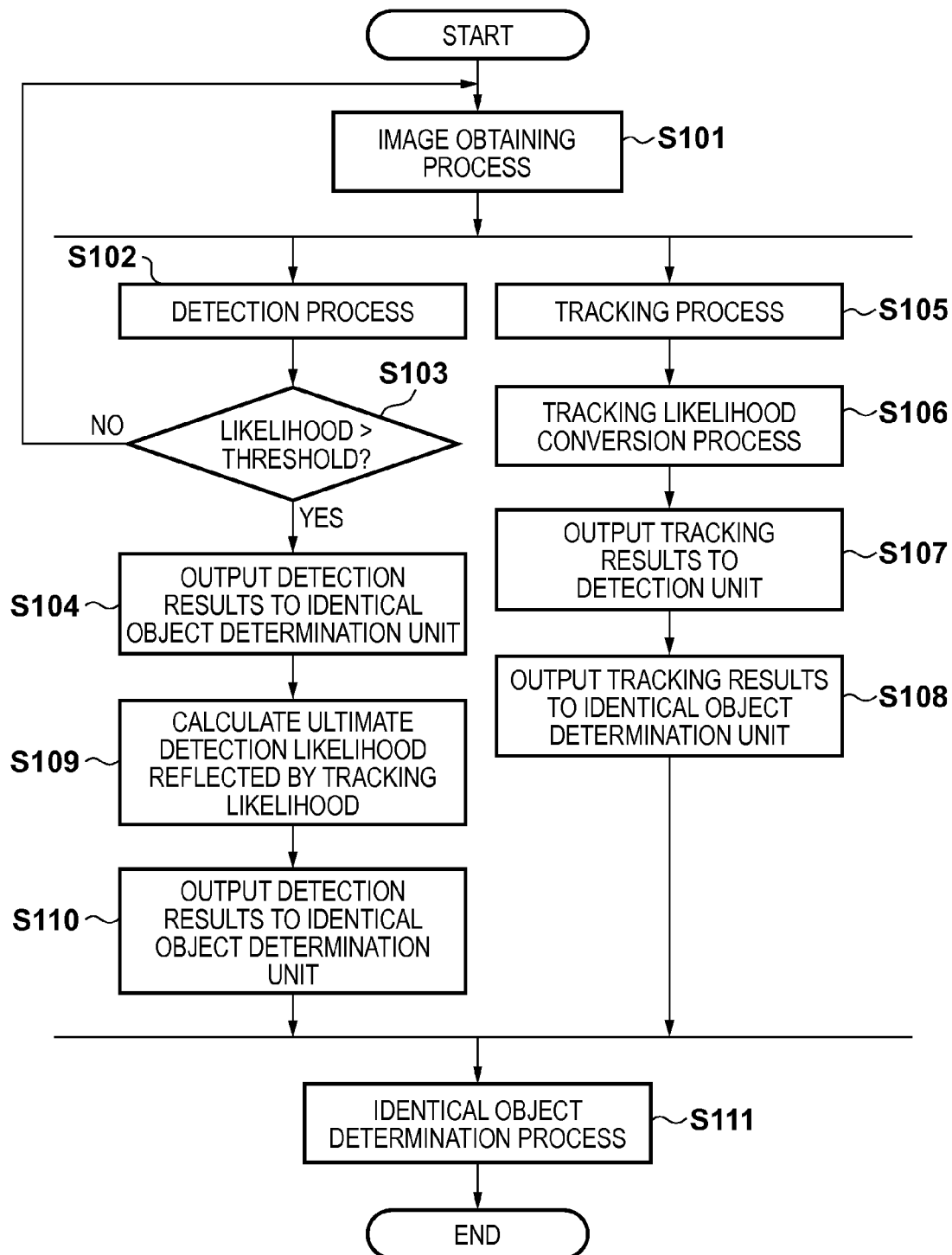U.S. Appl. No. 13/421,278, filed Mar. 15, 2012; Inventors: Yamanaka, et al.

Takeuchi et al., "Vehicle Tracking Using Deformable Model and Particle Filters", IEICE Technical Report, Japan, The Institute of Electronics, Information and Communication Engineers, vol. 109 No. 41, pp. 269-274, Feb. 8, 2010.
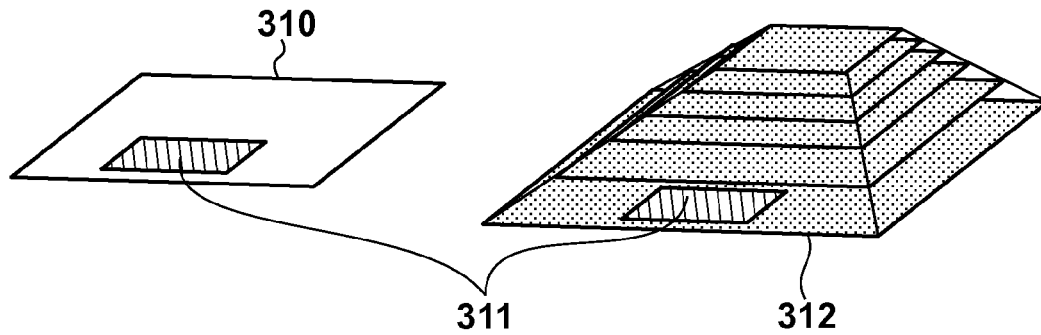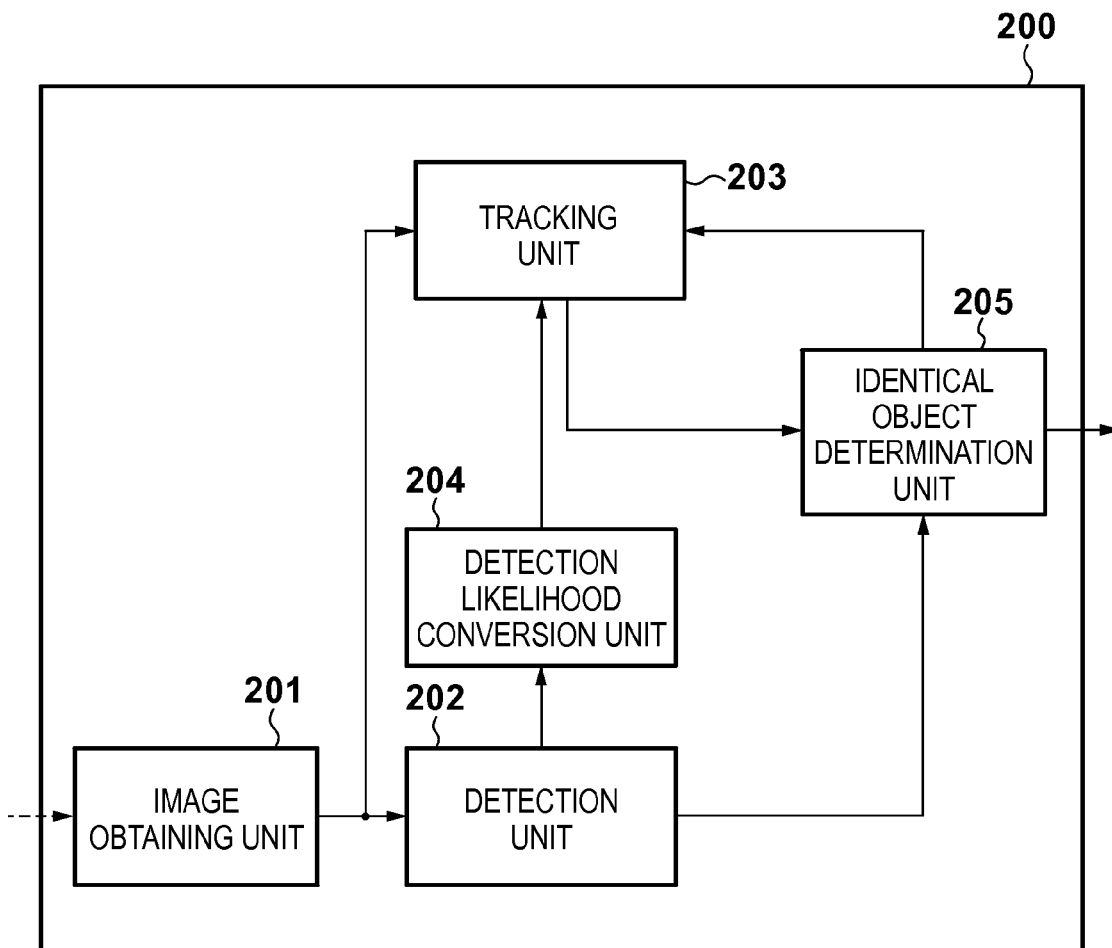
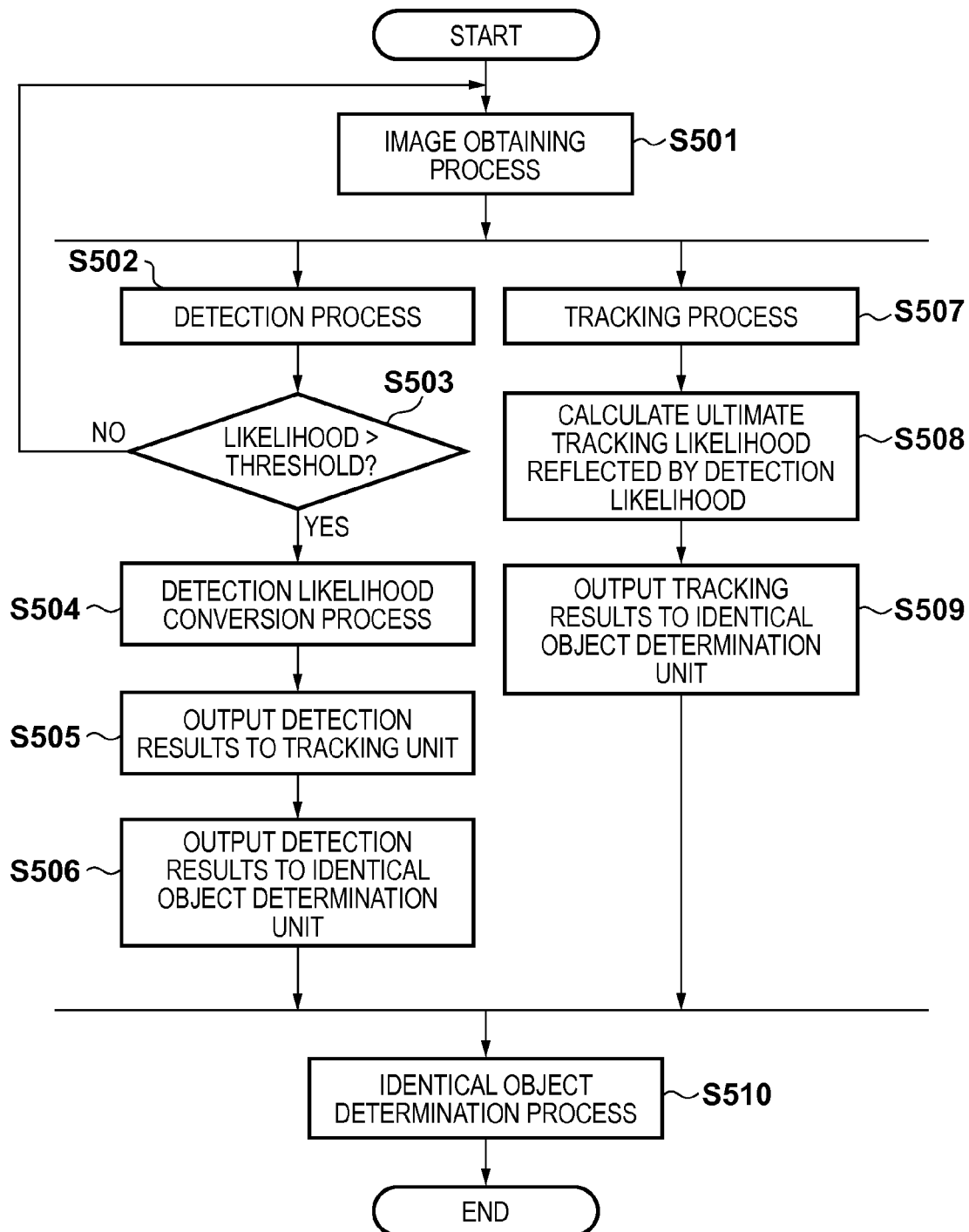Japanese Office Action issued Jul. 17, 2015 in Japanese Patent Application No. 2011-262655.

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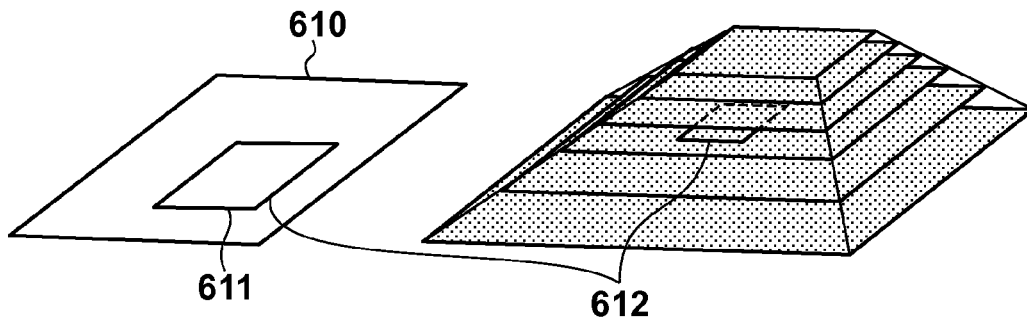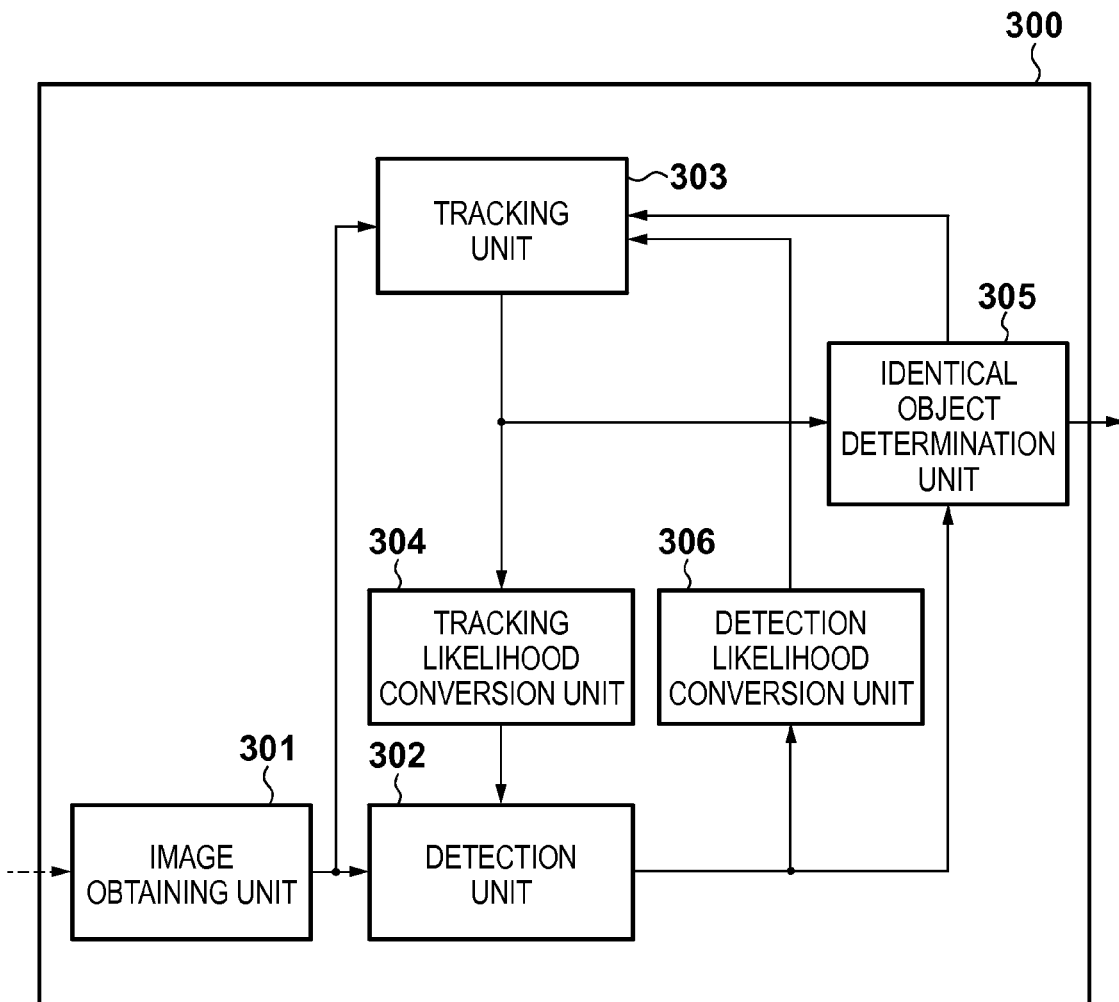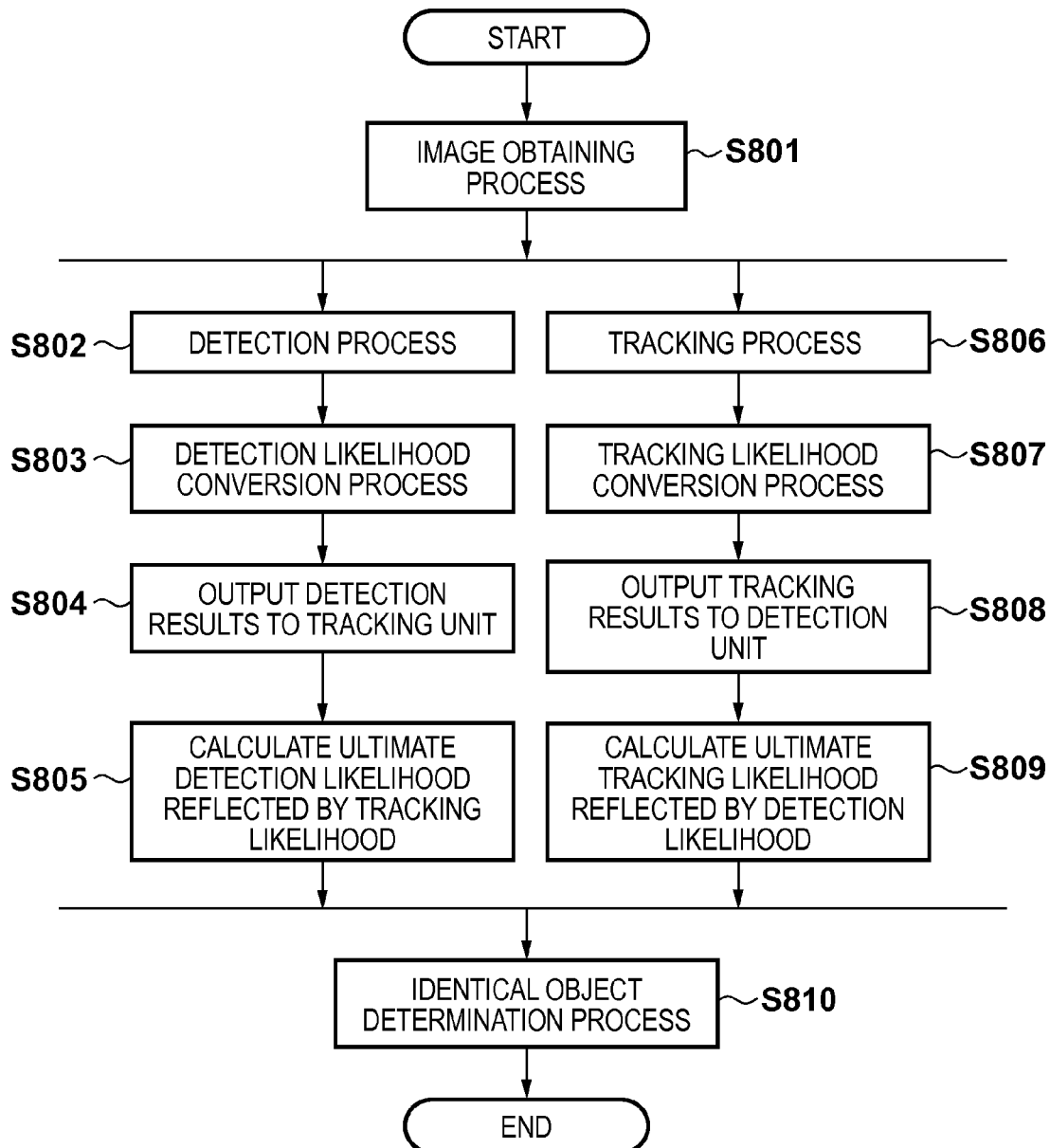# FIG. 1

100

103

TRACKING
UNIT

105

IDENTICAL
OBJECT
DETERMINATION
UNIT

104

TRACKING
LIKELIHOOD
CONVERSION UNIT

101

102

IMAGE
OBTAINING UNIT

DETECTION
UNIT

F I G. 2

```
                              ┌──────────┐
                              │  START   │
                              └──────────┘
                                   │
                    ┌──────────────────────────┐
                    │    IMAGE OBTAINING        │ ～S101
                    │       PROCESS             │
                    └──────────────────────────┘
                                   │
S102 ┌─────────────────────┐            ┌─────────────────────┐
     │  DETECTION PROCESS  │            │  TRACKING PROCESS   │ ～S105
     └─────────────────────┘            └─────────────────────┘
                 │                                  │
           S103  ◇                      ┌─────────────────────┐
      NO   ╱ LIKELIHOOD >  ╲            │ TRACKING LIKELIHOOD │ ～S106
   ◄───── ╱   THRESHOLD?    ╲           │ CONVERSION PROCESS  │
          ╲                 ╱           └─────────────────────┘
           ╲               ╱                        │
            ◇                             ┌─────────────────────┐
            │ YES                         │   OUTPUT TRACKING   │
     ┌─────────────────────┐             │    RESULTS TO       │ ～S107
S104 │  OUTPUT DETECTION   │             │   DETECTION UNIT    │
     │ RESULTS TO IDENTICAL│             └─────────────────────┘
     │OBJECT DETERMINATION │                        │
     │        UNIT         │            ┌──────────────────────────┐
     └─────────────────────┘            │ OUTPUT TRACKING RESULTS  │ ～S108
                 │                       │  TO IDENTICAL OBJECT     │
     ┌─────────────────────┐            │  DETERMINATION UNIT      │
     │ CALCULATE ULTIMATE  │             └──────────────────────────┘
S109 │ DETECTION LIKELIHOOD│                        │
     │ REFLECTED BY TRACKING│
     │     LIKELIHOOD      │
     └─────────────────────┘
                 │
     ┌─────────────────────┐
     │  OUTPUT DETECTION   │
S110 │   RESULTS TO        │
     │ IDENTICAL OBJECT    │
     │ DETERMINATION UNIT  │
     └─────────────────────┘
                 │
          ┌─────────────────────────┐
          │   IDENTICAL OBJECT      │ ～S111
          │ DETERMINATION PROCESS   │
          └─────────────────────────┘
                      │
                 ┌──────────┐
                 │   END    │
                 └──────────┘
```

F I G. 3

310

311   312

F I G. 4

200

TRACKING
UNIT
203

205

IDENTICAL
OBJECT
DETERMINATION
UNIT

204

DETECTION
LIKELIHOOD
CONVERSION UNIT

201   202

IMAGE
OBTAINING UNIT

DETECTION
UNIT

F I G. 5

START

IMAGE OBTAINING PROCESS ~S501

S502

DETECTION PROCESS

S503

NO — LIKELIHOOD > THRESHOLD?

YES

S504 — DETECTION LIKELIHOOD CONVERSION PROCESS

S505 — OUTPUT DETECTION RESULTS TO TRACKING UNIT

S506 — OUTPUT DETECTION RESULTS TO IDENTICAL OBJECT DETERMINATION UNIT

TRACKING PROCESS ~S507

CALCULATE ULTIMATE TRACKING LIKELIHOOD REFLECTED BY DETECTION LIKELIHOOD ~S508

OUTPUT TRACKING RESULTS TO IDENTICAL OBJECT DETERMINATION UNIT ~S509

IDENTICAL OBJECT DETERMINATION PROCESS ~S510

END

FIG. 6

610

611

612

FIG. 7

300

303

TRACKING
UNIT

305

IDENTICAL
OBJECT
DETERMINATION
UNIT

304

TRACKING
LIKELIHOOD
CONVERSION UNIT

306

DETECTION
LIKELIHOOD
CONVERSION UNIT

301

IMAGE
OBTAINING UNIT

302

DETECTION
UNIT

F I G. 8

```
                        ┌─────────────┐
                        │    START    │
                        └─────────────┘
                               │
                               ▼
                  ┌───────────────────────┐
                  │   IMAGE OBTAINING     │──S801
                  │      PROCESS          │
                  └───────────────────────┘
                               │
        ───────────────────────┼───────────────────────
                │                              │
                ▼                              ▼
    S802──┌──────────────────┐   ┌──────────────────┐──S806
          │ DETECTION PROCESS│   │ TRACKING PROCESS │
          └──────────────────┘   └──────────────────┘
                │                              │
                ▼                              ▼
    S803──┌──────────────────┐   ┌──────────────────┐──S807
          │ DETECTION        │   │ TRACKING         │
          │ LIKELIHOOD       │   │ LIKELIHOOD       │
          │ CONVERSION       │   │ CONVERSION       │
          │ PROCESS          │   │ PROCESS          │
          └──────────────────┘   └──────────────────┘
                │                              │
                ▼                              ▼
    S804──┌──────────────────┐   ┌──────────────────┐──S808
          │ OUTPUT DETECTION │   │ OUTPUT TRACKING  │
          │ RESULTS TO       │   │ RESULTS TO       │
          │ TRACKING UNIT    │   │ DETECTION UNIT   │
          └──────────────────┘   └──────────────────┘
                │                              │
                ▼                              ▼
    S805──┌──────────────────┐   ┌──────────────────┐──S809
          │ CALCULATE        │   │ CALCULATE        │
          │ ULTIMATE         │   │ ULTIMATE         │
          │ DETECTION        │   │ TRACKING         │
          │ LIKELIHOOD       │   │ LIKELIHOOD       │
          │ REFLECTED BY     │   │ REFLECTED BY     │
          │ TRACKING         │   │ DETECTION        │
          │ LIKELIHOOD       │   │ LIKELIHOOD       │
          └──────────────────┘   └──────────────────┘
                │                              │
        ────────┴──────────────┬───────────────┘
                               ▼
                  ┌───────────────────────┐
                  │   IDENTICAL OBJECT    │──S810
                  │ DETERMINATION PROCESS │
                  └───────────────────────┘
                               │
                               ▼
                        ┌─────────────┐
                        │     END     │
                        └─────────────┘
```

F I G. 9

400

405 IDENTICAL OBJECT DETERMINATION UNIT

406 DETECTION LIKELIHOOD CONVERSION UNIT

408 DETECTION LIKELIHOOD DISTRIBUTION UNIT

403

4033 TRACKING UNIT

4032 TRACKING UNIT

4031 TRACKING UNIT

TRACKING UNIT

404 TRACKING LIKELIHOOD CONVERSION UNIT

407 TRACKING LIKELIHOOD DISTRIBUTION UNIT

402

4023 DETECTION UNIT

4022 DETECTION UNIT

4021 DETECTION UNIT

DETECTION UNIT

401 IMAGE OBTAINING UNIT

F I G. 10

START

IMAGE OBTAINING PROCESS — S1001

S1002 — DETECTION PROCESS

TRACKING PROCESS — S1007

S1003 — DETECTION LIKELIHOOD CONVERSION PROCESS

TRACKING LIKELIHOOD CONVERSION PROCESS — S1008

S1004 — OUTPUT DETECTION RESULTS TO DETECTION LIKELIHOOD DISTRIBUTION UNIT

OUTPUT TRACKING RESULTS TO TRACKING LIKELIHOOD DISTRIBUTION UNIT — S1009

S1005 — DISTRIBUTE DETECTION LIKELIHOODS TO TRACKING UNITS

DISTRIBUTE TRACKING LIKELIHOODS TO DETECTION UNITS — S1010

S1006 — CALCULATE ULTIMATE DETECTION LIKELIHOOD REFLECTED BY TRACKING LIKELIHOOD

CALCULATE ULTIMATE TRACKING LIKELIHOOD REFLECTED BY DETECTION LIKELIHOOD — S1011

IDENTICAL OBJECT DETERMINATION PROCESS — S1012

END

OBJECT DETECTION APPARATUS, METHOD FOR CONTROLLING THE OBJECT DETECTION APPARATUS, AND STORAGE MEDIUM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an object detection apparatus for detecting a target object from an image, a method for controlling the object detection apparatus, and a storage medium.

2. Description of the Related Art

Methods for detecting a target object from an image with the use of previously learned models have been known. Navneet Dalal and Bill Triggs "Histogram of Oriented Gradients for Human Detection", IEEE CVPR2005 discloses a method in which a large number of images are prepared, features called HOG are extracted from the images and learned using SVM, and the target object is detected with the use of the learned models.

Unfortunately, however, in the method described in Navneet Dalal and Bill Triggs, "Histogram of Oriented Gradients for Human Detection", IEEE CVPR2005, change in pose or occlusion of the target object would deteriorate detection accuracy of the target object.

In view of the aforementioned problem, the present invention provides a technique which allows robust detection of a target object against change in pose or occlusion of the target object.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, there is provided an object detection apparatus comprising: an image obtaining unit configured to sequentially obtain a plurality of frame images; a detection unit configured to calculate a detection likelihood from each of the plurality of frame images, and to detect a target object from each of the frame images on the basis of the detection likelihood; and a tracking unit configured to calculate a tracking likelihood of the target object from each of the plurality of frame images, and to track the target object over the plurality of frame images on the basis of the tracking likelihood, wherein the detection unit detects the target object from the frame images obtained by the image obtaining unit on the basis of the tracking likelihood of the target object that is calculated by the tracking unit from the frame images, and the detection likelihood of the target object that is calculated by the detection unit from the frame images.

According to one aspect of the present invention, there is provided a method for controlling an object detection apparatus, comprising the steps of: sequentially obtaining a plurality of frame images; calculating a detection likelihood from each of the plurality of frame images, and detecting a target object from each of the frame images on the basis of the detection likelihood; calculating a tracking likelihood of the target object from each of the plurality of frame images, and tracking the target object over the plurality of frame images on the basis of the tracking likelihood; and wherein in the detecting step, the target object is detected from the frame images obtained in the image obtainment step on the basis of the tracking likelihood of the target object that is calculated in the tracking step from the frame images, and the detection likelihood of the target object that is calculated in the detection step from the frame images.

Further features of the present invention will be apparent from the following description of exemplary embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a configuration of an object detection apparatus according to Embodiment 1.

FIG. **2** is a flowchart illustrating a sequence of processing steps of the object detection apparatus according to Embodiment 1.

FIG. **3** is a diagram for explaining a processing of the object detection apparatus according to Embodiment 1.

FIG. **4** illustrates a configuration of an object detection apparatus according to Embodiment 2.

FIG. **5** is a flowchart illustrating a sequence of processing steps of the object detection apparatus according to Embodiment 2.

FIG. **6** is a diagram for explaining a processing of the object detection apparatus according to Embodiment 2.

FIG. **7** illustrates a configuration of an object detection apparatus according to Embodiment 3.

FIG. **8** is a flowchart illustrating a sequence of processing steps of the object detection apparatus according to Embodiment 3.

FIG. **9** illustrates a configuration of an object detection apparatus according to Embodiment 4.

FIG. **10** is a flowchart illustrating a sequence of processing steps of the object detection apparatus according to Embodiment 4.

DESCRIPTION OF THE EMBODIMENTS

An exemplary embodiments of the present invention will now be described in detail with reference to the drawings. It should be noted that the relative arrangement of the components, the numerical expressions and numerical values set forth in these embodiments do not limit the scope of the present invention unless it is specifically stated otherwise.

(Embodiment 1)

A configuration of an object detection apparatus **100** according to Embodiment 1 will be described with reference to FIG. **1**. The object detection apparatus **100** includes: an image obtaining unit **101**; a detection unit **102**; a tracking unit **103**; a tracking likelihood conversion unit **104**; and an identical object determination unit **105**. Operations of the units are controlled by a CPU (not illustrated).

The image obtaining unit **101** sequentially obtains a plurality of frame images. The image obtaining unit **101** can obtain a plurality of frame images photographed by a camera. Alternatively, the image obtaining unit **101** can obtain, from a memory, a plurality of frame images which were photographed in advance and stored in the memory. The obtained frame images are outputted to the detection unit **102** and the tracking unit **103**.

The detection unit **102** obtains the plurality of frame images outputted from the image obtaining unit **101**, and performs a detection process for detecting a target object from the obtained frame images. For the detection process, any of well-known techniques can be employed, such as one using HOG and SVM, as described in "histograms of oriented gradients for human detection", N. Dalal, CVPR2005; one using ISM, as described in "Combined Object Categorization and Segmentation with an Implicit Shape Model", B. Leibe, ECCV2004; and one using Latent-SVM, as described in "A Discriminatively Trained, MultiScale, Deformable Part Model", P. Felzenszwalb, CVPR2009. Detection results (po-

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sition information and size information on the target object) and a likelihood of the target object obtained by the detection process are outputted to the identical object determination unit 105.

The tracking unit 103 obtains the plurality of frame images outputted from the image obtaining unit 101, and performs a tracking process for tracking a target object with respect to the obtained frame images. That is, the tracking unit 103 calculates a tracking likelihood of the target object from each of the plurality of frame images, and tracks the target object over the plurality of frame images on the basis of the tracking likelihood thus calculated. For the tracking process, any of well-known techniques can be employed, such as one using Online Boosting, as described in H. Grabner, "Online Boosting and Vision", CVPR2006; and one using Condensation, as described in M. Isard A. Blake, "ICondensation: Unifying low-level and high-level tracking in a stochastic framework", ECCV1998. Note here that a target object to be tracked is decided on the basis of the position information and size information on the target object obtained from the identical object determination unit 105. Position information and size information and the likelihood of the target object obtained as the result of the tracking process are outputted to the tracking likelihood conversion unit 104 and the identical object determination unit 105.

The tracking likelihood conversion unit 104 obtains the tracking results outputted from the tracking unit 103 and converts, with reference to the obtained position information and size information and the likelihood of the target object, the likelihood into a form usable in the detection unit 102. For example, the tracking likelihood conversion unit 104 converts the likelihood to a normalized likelihood so that both the likelihood from the detection unit 102 and the likelihood from the tracking unit 103 can be compared with each other.

Specifically, as illustrated in FIG. 3, the tracking unit 103 calculates a likelihood of the target object to be tracked within a search range 311 in an image 310 of a certain scale on the basis of the position information and size information on the target object to be tracked. The search range 311 corresponds to a part of a processing range 312 of an image pyramid which is subjected to the detection process. The likelihood of the tracked target object is converted so as to be subjected to the likelihood calculation processing in the detection process. Note here that the image pyramid is configured to be a collection of images having various resolutions between a high resolution and a low resolution. The likelihood converted by the tracking likelihood conversion unit 104 is outputted to the detection unit 102. The detection unit 102 calculates an ultimate likelihood in a second or any subsequent frame by combining the likelihood obtained from the tracking likelihood conversion unit 104 with the likelihood of the target object in an image obtained by the detection process, and outputs the calculated ultimate likelihood to the identical object determination unit 105. Note here that the ultimate likelihood can be calculated by obtaining an additional value, average value or the like, of the both normalized likelihoods. If such a value is more than a threshold, then it can be determined to be of the target object.

The identical object determination unit 105 refers to the detection results outputted from the detection unit 102 and the tracking results outputted from the tracking unit 103, and determines whether or not the detection results and the tracking results represent the identical target object. For example, as given by Formulae (1) and (2), the position information and the size information on the target object ("detection") obtained from the detection results are compared with those on the tracked target object ("tracking"). When the compari-

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son determines that the positions are substantially the same (the distance is substantially zero) as shown by Formulae (1) and the sizes are substantially the same (the ratio of the sizes is substantially one) as shown by Formulae (2), then the identical object determination unit 105 determines that both results represent the identical target object.

[Formula 1]

$$\text{distance(detection, tracking)} \cong 0 \tag{1}$$

[Formula 2]

$$\frac{\text{size(detection)}}{\text{size(tracking)}} \cong 1 \tag{2}$$

Alternatively, it is also possible to determine stochastically, i.e. by applying positions and sizes to a Gaussian distribution, whether or not both results represent the identical target object. Alternatively, detection results and tracking results can be provided in a proportion of one to one. The result determined by the identical object determination unit 105 is to be regarded as an ultimate detection result. Alternatively, it can be determined whether or not a difference between the ultimate tracking likelihood calculated by the tracking unit 103 and the detection likelihood calculated by the detection unit 102 lies within a certain range, in order to determine that both results represent the identical target object. When it is determined that both results represent the identical target object, such determination result will be outputted to the tracking unit 103, and the tracking unit 103 will maintain the tracking process. On the other hand, when it is determined that both results do not represent the identical target object, that is, in a case where, for example, a new target object is additionally detected, such determination result will be outputted to the tracking unit 103, and the tracking unit 103 will perform an additional tracking process with respect to the new target object.

Referring now to a flowchart of FIG. 2, processing steps to be performed by the object detection apparatus 100 of Embodiment 1 will be described. It should be noted that program codes in accordance with the flowchart are stored in a memory (not illustrated), such as RAM or ROM, and will be read out for execution by a CPU (not illustrated).

In a step S101, the image obtaining unit 101 obtains a plurality of frame images from photographic equipment, an image file, or the like. The obtained frame images are outputted to the detection unit 102 and the tracking unit 103. In a step S102, the detection unit 102 performs a detection process for detecting a target object from the plurality of frame images obtained in the step S101. In a step S103, the detection unit 102 determines whether or not a likelihood which is obtained by the detection process is more than a threshold. When the likelihood is determined to be more than the threshold (S103; YES), it is possible to determine that a target object is detected in that position and that size. Accordingly, the processing goes to a step S104. On the other hand, when the likelihood is determined to be less than the threshold (S103; NO), it is possible to determine that a target object is not detected. Accordingly, the processing goes back to the step S101.

In the step S104, the detection unit 102 outputs the detection results to the identical object determination unit 105. In a step S105, the tracking unit 103 performs a tracking process for tracking a target object with respect to the plurality of frame images obtained from the image obtaining unit 101.

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Note here that a target object to be tracked is decided on the basis of the position information and size information on the target object obtained from the identical object determination unit **105**. Position information and size information and a likelihood of the target object obtained as the result of the tracking process are outputted to the tracking likelihood conversion unit **104** and the identical object determination unit **105**. Then, the processing goes to a step S**106**.

In the step S**106**, the tracking likelihood conversion unit **104** converts, with reference to the tracking results obtained from the tracking unit **103**, in particular, the position information and size information and the likelihood of the target object, the likelihood into a form usable in the detection unit **102**.

In a step S**107**, the tracking likelihood conversion unit **104** outputs the likelihood converted in the step S**106** to the detection unit **102**. In a step S**108**, the tracking unit **103** outputs the tracking results to the identical object determination unit **105**.

In a step S**109**, the detection unit **102** calculates an ultimate likelihood by combining the likelihood obtained from the tracking likelihood conversion unit **104** with the likelihood in an image obtained by the detection process. In a step S**110**, the detection unit **102** outputs the calculated ultimate likelihood to the identical object determination unit **105**. Subsequently, the processing goes to a step S**111**.

In the step S**111**, the identical object determination unit **105** refers to the detection results from the detection unit **102** and the tracking results from the tracking unit **103**, and determines whether or not the detection results and the tracking results represent the identical target object. For example, as given by Formulae (1) and (2), the position information and the size information on the target object obtained from the detection results are compared with those on the tracked target object. When the comparison determines that the positions are substantially the same and the sizes are substantially the same, then the identical object determination unit **105** determines that both results represent the identical target object. The identical object determination unit **105** outputs such determination result and ends the processing. All the steps in the flowchart of FIG. **2** thus end.

As has been described above, according to the present embodiment, the tracking results obtained by the tracking unit are reflected on the detection results obtained by the detection unit. Therefore, the present embodiment improves detection accuracy in the detection process in a second or any subsequent frame (a second detection process), allowing robust detection of a target object against change in pose or occlusion of the target object.

(Embodiment 2)

A configuration of an object detection apparatus **200** according to Embodiment 2 will be described with reference to FIG. **4**. The object detection apparatus **200** includes: an image obtaining unit **201**; a detection unit **202**; a tracking unit **203**; a detection likelihood conversion unit **204**; and an identical object determination unit **205**. The object detection apparatus **100** of Embodiment 1 includes the tracking likelihood conversion unit **104**, whereas the object detection apparatus **200** of Embodiment 2 includes the detection likelihood conversion unit **204**, instead of the tracking likelihood conversion unit **104**.

The image obtaining unit **201** has the same function as that of the image obtaining unit **101**, and therefore a description thereof is omitted.

The detection unit **202** obtains a plurality of frame images outputted from the image obtaining unit **201**, and performs a detection process for detecting a target object from the obtained frame images. Detection results (position informa-

tion and size information on the target object) and a likelihood of the target object obtained by the detection process are outputted to the detection likelihood conversion unit **204** and the identical object determination unit **205**.

The tracking unit **203** obtains the plurality of frame images outputted from the image obtaining unit **201**, and performs a tracking process for tracking a target object with respect to the obtained frame images. Note here that a target object to be tracked is decided on the basis of the position information and size information on the target object obtained from the identical object determination unit **205**. Position information and size information and a likelihood of the target object obtained as the result of the tracking process are outputted to the identical object determination unit **205**.

The detection likelihood conversion unit **204** obtains the detection results outputted from the detection unit **202** and converts, with reference to the obtained detection results, in particular, the position information and size information and the likelihood of the target object, the likelihood into a form usable in the tracking unit **203**. Specifically, as illustrated in FIG. **6**, on the basis of the position information and size information on the detected target object, a likelihood map **611** in an image **610** of a certain scale is determined. The detection likelihood conversion unit **204** extracts a likelihood of a range **612** which corresponds to the likelihood map **611** obtained from the detection process results, and converts the extracted likelihood so that it matches the normalized likelihood range outputted from the tracking unit **203**. The detection likelihood converted by the likelihood conversion unit **204** is outputted to the tracking unit **203**. The tracking unit **203** calculates an ultimate likelihood in a second or any subsequent frame by combining the likelihood obtained from the detection likelihood conversion unit **204** with the likelihood of the target object in an image obtained by the tracking process, and outputs the calculated ultimate likelihood to the identical object determination unit **205**.

The identical object determination unit **205** refers to the detection results outputted from the detection unit **202** and the tracking results outputted from the tracking unit **203**, and determines whether or not the detection results and the tracking results represent the identical target object. In the same way as Embodiment 1, as given by Formulae (1) and (2), the position information and the size information on the target object obtained from the detection results are compared with those on the tracked target object. When the comparison determines that the positions are substantially the same and the sizes are substantially the same, then the identical object determination unit **205** determines that both results represent the identical target object.

Referring now to a flowchart of FIG. **5**, processing steps to be performed by the object detection apparatus **200** of Embodiment 2 will be described. Processes in steps S**501** and S**502** are equivalent to those in the steps S**101** and S**102**, and therefore descriptions thereof are omitted.

In a step S**503**, the detection unit **202** determines whether or not a likelihood obtained by the detection process is more than a threshold. When the likelihood is determined to be more than the threshold (S**503**; YES), it is possible to determine that a target object is detected in that position and that size. Accordingly, the detection unit **202** outputs the detection results to the detection likelihood conversion unit **204**. The processing thus goes to a step S**504**. On the other hand, when the likelihood value is determined to be less than the threshold (S**503**; NO), it is possible to determine that the target object is not detected. Accordingly, the processing goes back to the step S**501**.

In the step S504, the detection likelihood conversion unit 204 obtains the detection results outputted from the detection unit 202, and converts, with reference to the obtained detection results, in particular, the position information and size information and the likelihood of the target object, the likelihood into a form usable in the tracking unit 203.

In a step S505, the detection likelihood conversion unit 204 outputs the likelihood converted in the step S504 to the tracking unit 203. In a step S506, the detection unit 202 outputs the detection results to the identical object determination unit 205.

In a step S507, the tracking unit 203 performs a tracking process for tracking a target object with respect to the plurality of frame images obtained from the image obtaining unit 201. Note here that a target object to be tracked is decided on the basis of the position information and size information on the target object obtained from the identical object determination unit 205.

In a step S508, the tracking unit 203 calculates an ultimate likelihood, taking into consideration the likelihood obtained from the detection likelihood conversion unit 204, and determines a position of the tracked target object. In a step S509, the tracking unit 203 outputs the position information and size information and the likelihood of the target object, which have been obtained as the result of the tracking process, to the identical object determination unit 205.

A process in a step S510 is equivalent to that of the step S111, and therefore a description thereof is omitted. All the steps in the flowchart of FIG. 5 thus end.

As has been described above, according to the present embodiment, the detection results obtained by the detection unit are reflected on the tracking results obtained by the tracking unit. Therefore, the present embodiment improves tracking accuracy in the tracking process in a second or any subsequent frame (a second tracking process), allowing robust tracking of a target object against change in pose or occlusion of the target object.

(Embodiment 3)

A configuration of an object detection apparatus 300 according to Embodiment 3 will be described with reference to FIG. 7. The object detection apparatus 300 includes: an image obtaining unit 301; a detection unit 302; a tracking unit 303; a tracking likelihood conversion unit 304; an identical object determination unit 305; and a detection likelihood conversion unit 306. While the object detection apparatus 100 of Embodiment 1 includes the tracking likelihood conversion unit 104, and the object detection apparatus 200 of Embodiment 2 includes the detection likelihood conversion unit 204. The object detection apparatus 300 of Embodiment 3 includes both the tracking likelihood conversion unit 304 and the detection likelihood conversion unit 306. The image obtaining unit 301 has the same function as that of the image obtaining unit 101, and therefore a description thereof is omitted.

The detection unit 302 obtains a plurality of frame images outputted from the image obtaining unit 301, and performs a detection process for detecting a target object from the obtained frame images. Detection results (position information and size information on the target object) and a likelihood of the target object obtained by the detection process are outputted to the detection likelihood conversion unit 306 and the identical object determination unit 305.

The tracking unit 303 obtains the plurality of frame images outputted from the image obtaining unit 301, and performs a tracking process for tracking a target object with respect to the obtained frame images. Note here that a target object to be tracked is decided on the basis of the position information and

size information on the target object obtained from the identical object determination unit 305. Position information and size information and a likelihood of the target object obtained as the result of the tracking process are outputted to the tracking likelihood conversion unit 304 and the identical object determination unit 305.

The tracking likelihood conversion unit 304 obtains the tracking results outputted from the tracking unit 303, and converts, with reference to the obtained position information and size information and the likelihood of the target object, the likelihood into a form usable in the detection unit 302. The likelihood converted by the tracking likelihood conversion unit 304 is outputted to the detection unit 302. The detection unit 302 calculates an ultimate likelihood in a second or any subsequent frame by combining the likelihood obtained from the tracking likelihood conversion unit 304 with the likelihood of the target object in an image obtained by the detection process, and outputs the calculated ultimate likelihood to the identical object determination unit 305.

The detection likelihood conversion unit 306 obtains the detection results outputted from the detection unit 302 and converts, with reference to the obtained detection results, in particular, the position information and size information and the likelihood of the target object, the likelihood to a form usable in the tracking unit 303. The likelihood converted by the detection likelihood conversion unit 306 is outputted to the tracking unit 303. The tracking unit 303 calculates an ultimate likelihood in a second or any subsequent frame by combining the likelihood obtained from the detection likelihood conversion unit 306 with the likelihood of the target object in an image obtained by the tracking process, and outputs the calculated ultimate likelihood to the identical object determination unit 305.

The identical object determination unit 305 refers to the detection results outputted from the detection unit 302 and the tracking results outputted from the tracking unit 303, and determines whether or not the detection results and the tracking results represent the identical target object. In the same way as Embodiment 1, as given by Formulae (1) and (2), the position information and the size information on the target object obtained from the detection results are compared with those on the tracked target object. When the comparison determines that the positions are substantially the same and the sizes are substantially the same, then the identical object determination unit 305 determines that both results represent the identical target object.

Referring now to a flowchart of FIG. 8, processing steps to be performed by the object detection apparatus 300 of Embodiment 3 will be described. Processes in steps S802 through S805 are executed in parallel to processes in steps S806 through S809. A process in a step S801 is equivalent to that in the step S101 and therefore a description thereof is omitted.

In a step S802, the detection unit 302 obtains the plurality of frame images outputted from the image obtaining unit 301, and performs a detection process for detecting a target object from the obtained frame images. Detection results (position information and size information on the target object) and a likelihood of the target object obtained by the detection process are outputted to the detection likelihood conversion unit 306 and the identical object determination unit 305.

In a step S803, the detection likelihood conversion unit 306 obtains the detection results outputted from the detection unit 302 and converts, with reference to the obtained detection results, in particular, the position information and size information and the likelihood of the target object, the likelihood into a form usable in the tracking unit 303.

In a step **S804**, the detection likelihood conversion unit **306** outputs the likelihood converted in the step **S803** to the tracking unit **303**. In a step **S805**, the detection unit **302** calculates an ultimate likelihood by combining the likelihood obtained from the tracking likelihood conversion unit **304** with the likelihood of the target object in an image obtained by the detection process, and outputs the calculated ultimate likelihood to the identical object determination unit **305**.

In a step **S806**, the tracking unit **303** obtains the plurality of frame images outputted from the image obtaining unit **301**, and performs a tracking process for tracking a target object with respect to the obtained frame images. Note here that a target object to be tracked is decided on the basis of the position information and size information on the target object obtained from the identical object determination unit **305**. Position information and size information and a likelihood of the target object obtained as the result of the tracking process are outputted to the tracking likelihood conversion unit **304** and the identical object determination unit **305**.

In a step **S807**, the tracking likelihood conversion unit **304** obtains the tracking results outputted from the tracking unit **303** and converts, with reference to the obtained position information and size information and the likelihood of the target object, the likelihood into a form usable in the detection unit **302**.

In a step **S808**, the tracking likelihood conversion unit **304** outputs the likelihood converted in the step **S807** to the detection unit **302**. In a step **S809**, the tracking unit **303** calculates an ultimate likelihood by combining the likelihood obtained from the detection likelihood conversion unit **306** with the likelihood of the target object in an image obtained by the tracking process, and outputs the calculated ultimate likelihood to the identical object determination unit **305**.

A process in a step **S810** is equivalent to that in a step **S111** and therefore a description thereof is omitted. All the steps in the flowchart of FIG. **7** thus end. As has been described above, according to the present embodiment, a complementary process is carried out such that the process results of both the detection process and the tracking process are reflected on each other. This allows the present embodiment to provide robust detection and tracking of a target object against change in pose or occlusion of the target object.

(Embodiment 4)

A configuration of an object detection apparatus **400** according to Embodiment 4 will be described with reference to FIG. **9**. The object detection apparatus **400** includes: an image obtaining unit **401**; a detection unit **402**; a tracking unit **403**; a tracking likelihood conversion unit **404**; an identical object determination unit **405**; a detection likelihood conversion unit **406**; a tracking likelihood distribution unit **407**; and a detection likelihood distribution unit **408**. The detection unit **402** includes a plurality of detection units, such as a detection unit **4021**, a detection unit **4022**, and a detection unit **4023**. Similarly, the tracking unit **403** includes a plurality of tracking units, such as a tracking unit **4031**, a tracking unit **4032**, and a tracking unit **4033**. A detection unit and a tracking unit can be provided respectively for each part to be detected and to be tracked of a target object.

The object detection apparatus **400** of Embodiment 4 differs from the object detection apparatus **300** of Embodiment 3, in that the object detection apparatus **400** includes, in addition to the configuration of object detection apparatus **300**, the tracking likelihood distribution unit **407** and the detection likelihood distribution unit **408**, and that the detection unit **402** and the tracking unit **403** include one or more detection units and one or more tracking units, respectively. While the present embodiment discusses a configuration in

which three detection units and three tracking units are provided, it should be noted that the number of each unit is not necessarily three. The detection unit **4021** can detects an entire region of a target object. The detection unit **4022** can detect a face region if the target object is a human. And, the detection unit **4023** can detect another region of the human, such as hands or feet. Similarly, the tracking units **4031**, **4032**, and **4033** can respectively track the corresponding regions that the detection units have detected.

The image obtaining unit **401**, the detection unit **402**, the tracking unit **403**, the tracking likelihood conversion unit **404**, and the identical object determination unit **405** perform the same process as those of the respectively corresponding units of Embodiment 3, and therefore descriptions thereof are omitted.

The tracking likelihood distribution unit **407** distributes likelihoods which are outputted respectively from the tracking units **4031**, **4032**, and **4033** that constitute the tracking unit **403**, and converted by the tracking likelihood conversion unit **404**, to the detection units **4021**, **4022**, and **4023** that constitute the detection unit **402** and respectively correspond to the tracking units. The distribution is carried out on the basis of information on a model detected by the detection unit **402**, and information on a target model tracked by the tracking unit **403**. For example, in a case where the tracking unit **4031** tracked an entire region of a human, the tracking likelihood distribution unit **407** distributes the likelihood to the detection unit **4021** associated with an entire body of a human model. In a case where the tracking unit **4032** tracked a face region of the human, the tracking likelihood distribution unit **407** distributes the likelihood to the detection unit **4022** associated with a face region of the human model. In a case where the tracking unit **4033** tracked another region of the human, such as hands or feet, the tracking likelihood distribution unit **407** distributes the likelihood to the corresponding detection unit **4023** associated with another region of the human model.

The detection likelihood distribution unit **408** distribute likelihoods which are outputted from the detection units **4021**, **4022**, and **4023** that constitute the detection unit **402**, and converted by the detection likelihood conversion unit **406**, to the tracking units **4031**, **4032**, and **4033** that constitute the tracking unit **403** and respectively correspond to the detection units. The distribution is carried out on the basis of information on a target model detected by the detection unit **402**, and information on a target model tracked by the tracking unit **403**. For example, in a case where the detection unit **4021** detected an entire region of a human, the detection likelihood distribution unit **408** distributes the likelihood to the corresponding tracking unit **4031**. In a case where the detection unit **4022** detected a face region of the human, the detection likelihood distribution unit **408** distributes the likelihood to the corresponding tracking unit **4032**. In a case where the detection unit **4023** detected another region of the human, such as hands or feet, the detection likelihood distribution unit **408** distributes the likelihood to the corresponding tracking unit **4033**.

Referring now to a flowchart of FIG. **10**, processing steps to be performed by the object detection apparatus **400** of Embodiment 4 will be described. Processes in steps **S1001** through **S1003** are equivalent to those in the steps **S801** through **S803**, and therefore descriptions thereof are omitted. In a step **S1004**, the detection likelihood conversion unit **406** outputs the likelihoods converted in a step **S1003** to the detection likelihood distribution unit **408**.

In a step **S1005**, the detection likelihood distribution unit **408** distributes the likelihoods which are outputted from the detection units **4021**, **4022**, and **4023** that constitute the detec-

tion unit **402**, and converted by the detection likelihood conversion unit **406**, to the tracking units **4031**, **4032**, and **4033** that constitute the tracking unit **403** and respectively correspond to the detection units. The distribution is carried out on the basis of information on a target model detected by the detection unit **402**, and information on a target model tracked by the tracking unit **403**.

In a step S**1006**, the detection unit **402** calculates ultimate likelihood by combining likelihoods obtained from the tracking likelihood distribution unit **407**, with the likelihoods of the target object in images obtained by the detection process, and then outputs the calculated ultimate likelihood to the identical object determination unit **405**.

Processes in steps S**1007** through S**1008** are equivalent to those in the steps S**806** through S**807**, and therefore descriptions thereof are omitted. In a step S**1009**, the tracking likelihood conversion unit **404** outputs the likelihoods converted in the step S**1008** to the tracking likelihood distribution unit **407**.

In a step S**1010**, the tracking likelihood distribution unit **407** distributes the likelihoods which are outputted from the tracking units **4031**, **4032**, and **4033** that constitute the tracking unit **403**, and converted by the tracking likelihood conversion unit **404**, to the detection units **4021**, **4022**, and **4023** that constitute the detection unit **402** and respectively correspond to the detection units. The distribution is carried out on the basis of information on a model detected by the detection unit **402**, and information on a target model tracked by the tracking unit **403**.

In a step S**1011**, the tracking unit **403** calculates ultimate likelihood by combining the likelihoods obtained from the detection likelihood distribution unit **408**, with the likelihoods of the target object in images obtained by the tracking process, and then outputs the calculated ultimate likelihood to the identical object determination unit **405**. A process in a step S**1012** is equivalent to that in the step S**809**, and therefore a description thereof is omitted. All the steps in the flowchart of FIG. **10** thus end.

As has been described above, according to the present embodiment, a complementary process is carried out such that both the results of the detection process and the tracking process are reflected on each other for each region of a target object. Therefore, the present embodiment allows robust detection and tracking of a target object against change in pose or occlusion of the target object.

According to the present invention, robust detection of a target object can be attained against change in pose or occlusion of the target object.

Other Embodiments

Aspects of the present invention can also be realized by a computer of a system or apparatus (or devices such as a CPU or MPU) that reads out and executes a program recorded on a memory device to perform the functions of the above-described embodiment(s), and by a method, the steps of which are performed by a computer of a system or apparatus by, for example, reading out and executing a program recorded on a memory device to perform the functions of the above-described embodiment(s). For this purpose, the program is provided to the computer for example via a network or from a recording medium of various types serving as the memory device (e.g., computer-readable medium).

While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

This application claims the benefit of Japanese Patent Application No. 2011-262655, filed on Nov. 30, 2011, which is hereby incorporated by reference herein in its entirety.

What is claimed is:

1. An object detection apparatus comprising:

at least one processor and memory coupled to each other and cooperating to act as:

an image obtaining unit configured to sequentially obtain a plurality of frame images;

a detection unit configured to calculate a detection likelihood from an image pyramid generated by enlarging or reducing each of the plurality of frame images, and to detect a target object from each of the frame images on the basis of the detection likelihood;

a tracking unit configured to calculate a tracking likelihood of the target object from each of the plurality of frame images, and to track the target object over the plurality of frame images on the basis of the tracking likelihood, and,

a tracking likelihood conversion unit configured to convert the tracking likelihood of the target object so as to be subject to a likelihood calculation processing in a detection processing, on the basis of position information and size information on the target object,

wherein the detection unit detects the target object from the frame images obtained by the image obtaining unit on the basis of the converted tracking likelihood of the target object, and the detection likelihood of the target object that is calculated by the detection unit from the frame images.

2. The object detection apparatus according to claim **1**, further comprising:

a detection likelihood conversion unit configured to convert the detection likelihood of the target object so as to be subjected to the likelihood calculation processing in a tracking processing, on the basis of position information and size information on the target object,

wherein

the tracking unit tracks the target object on the basis of the tracking likelihood of the target object that is calculated by the tracking unit from the frame images obtained by the image obtaining unit and the converted detection likelihood of the target object.

3. The object detection apparatus according to claim **1**, wherein

the detection unit includes a plurality of detection units configured to detect respective parts of the target object, the number of the detection units depending on the number of the parts to be detected of the target object,

the tracking unit includes a plurality of tracking units configured to track the respective parts of the target object, the plurality of tracking units respectively corresponding to the plurality of detection units, the number of the tracking units depending on the number of the parts to be tracked of the target object,

the tracking likelihood conversion unit is configured to convert a plurality of tracking likelihoods of the target object so as to be subjected to the likelihood calculation processing in the detection processing, on the basis of position information and size information on the target object,

and

the detection unit detects the target object from the frame images obtained by the image obtaining unit on the basis of the plurality of tracking likelihoods of the target object that are converted by the tracking likelihood conversion unit and a plurality of detection likelihoods of

the target object that are calculated by the plurality of detection units from the frame images.

4. The object detection apparatus according to claim **3**, wherein

the detection likelihood conversion unit is configured to convert a plurality of detection likelihoods of the target object so as to be subjected to the likelihood calculation processing in a tracking processing, on the basis of position information and size information on the target object, and

the tracking unit tracks the target object on the basis of the plurality of tracking likelihoods of the target object that are calculated by the plurality of tracking units from the frame images obtained by the image obtaining unit, and the plurality of detection likelihoods of the target object that are converted by the detection likelihood conversion unit.

5. An object detection apparatus comprising:

at least one processor and memory coupled to each other and cooperating to act as:

an image obtaining unit configured to sequentially obtain a plurality of frame images;

a detection unit configured to calculate a detection likelihood from an image pyramid generated by enlarging or reducing each of the plurality of frame images, and to detect a target object from each of the frame images on the basis of the detection likelihood;

a tracking unit configured to calculate a tracking likelihood of the target object from each of the plurality of frame images, and to track the target object over the plurality of frame images on the basis of the tracking likelihood, and

a detection likelihood conversion unit configured to convert the detection likelihood of the target object so as to be subjected to a likelihood calculation processing in a tracking processing, on the basis of position information and size information on the target object,

wherein the tracking unit tracks the target object on the basis of the tracking likelihood of the target object that is calculated by the tracking unit from the frame images obtained by the image obtaining unit, and the converted detection likelihood of the target object.

6. A method for controlling an object detection apparatus, comprising the steps of:

sequentially obtaining a plurality of frame images;

calculating a detection likelihood from an image pyramid generated by enlarging or reducing each of the plurality of frame images, and detecting a target object from each of the frame images on the basis of the detection likelihood;

calculating a tracking likelihood of the target object from each of the plurality of frame images, and tracking the target object over the plurality of frame images on the basis of the tracking likelihood;

converting the tracking likelihood of the target object so as to be subjected to a likelihood calculation processing in a detection processing, on the basis of position information and size information on the target object; and

wherein in the detecting step, the target object is detected from the frame images obtained in the image obtainment step on the basis of the converted tracking likelihood of the target object, and the detection likelihood of the target object that is calculated in the detection step from the frame images.

7. A method for controlling an object detection apparatus, comprising the steps of:

sequentially obtaining a plurality of frame images;

calculating a detection likelihood from an image pyramid generated by enlarging or reducing each of the plurality of frame images, and detecting a target object from each of the frame images on the basis of the detection likelihood;

calculating a tracking likelihood of the target object from each of the plurality of frame images, and tracking the target object over the plurality of frame images on the basis of the tracking likelihood;

converting the detection likelihood of the target object so as to be subjected to a likelihood calculation processing in a tracking processing, on the basis of position information and size information on the target object; and

wherein in the tracking step, the target object is tracked on the basis of the tracking likelihood of the target object that is calculated in the tracking step from the frame images obtained in the image obtainment step, and the converted detection likelihood of the target object.

8. A non-transitory computer-readable storage medium storing a computer program for causing a computer to execute the steps of a method for controlling an object detection apparatus, comprising the steps of:

sequentially obtaining a plurality of frame images;

calculating a detection likelihood from an image pyramid generated by enlarging or reducing each of the plurality of frame images, and detecting a target object from each of the frame images on the basis of the detection likelihood;

calculating a tracking likelihood of the target object from each of the plurality of frame images, and tracking the target object over the plurality of frame images on the basis of the tracking likelihood;

converting the tracking likelihood of the target object so as to be subjected to a likelihood calculation processing in a detection processing, on the basis of position information and size information on the target object; and

wherein in the detecting step, the target object is detected from the frame images obtained in the image obtainment step on the basis of the converted tracking likelihood of the target object, and the detection likelihood of the target object that is calculated in the detection step from the frame images.

9. A non-transitory computer-readable storage medium storing a computer program for causing a computer to execute the steps of a method for controlling an object detection apparatus, comprising the steps of:

sequentially obtaining a plurality of frame images;

calculating a detection likelihood from an image pyramid generated by enlarging or reducing each of the plurality of frame images, and detecting a target object from each of the frame images on the basis of the detection likelihood;

calculating a tracking likelihood of the target object from each of the plurality of frame images, and tracking the target object over the plurality of frame images on the basis of the tracking likelihood;

converting the detection likelihood of the target object so as to be subjected to a likelihood calculation processing in a tracking processing, on the basis of position information and size information on the target object,

wherein in the tracking step, the target object is tracked on the basis of the tracking likelihood of the target object that is calculated in the tracking step from the frame images obtained in the image obtainment step, and the converted detection likelihood of the target object.

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